(ECOP-award) A bio-economic approach for supporting adaptation to climate change in capture fisheries: a case study of Korean squid fisheries utilizing Automated Identification System and environmental data

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Ex-Shrimp Farmer (2013-2022) -> Current PH.D Student



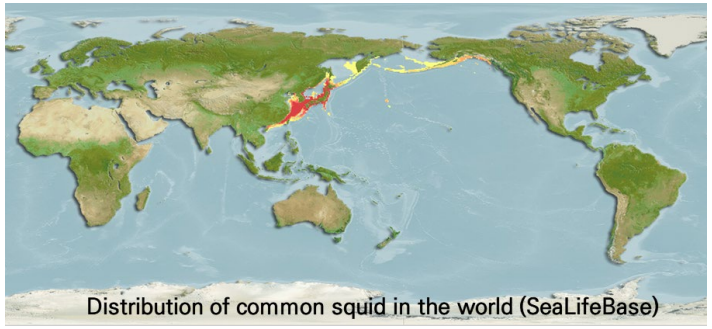




How fishers put more money in their pocket?

Target species: Common squid (*Todarodes pacificus*)

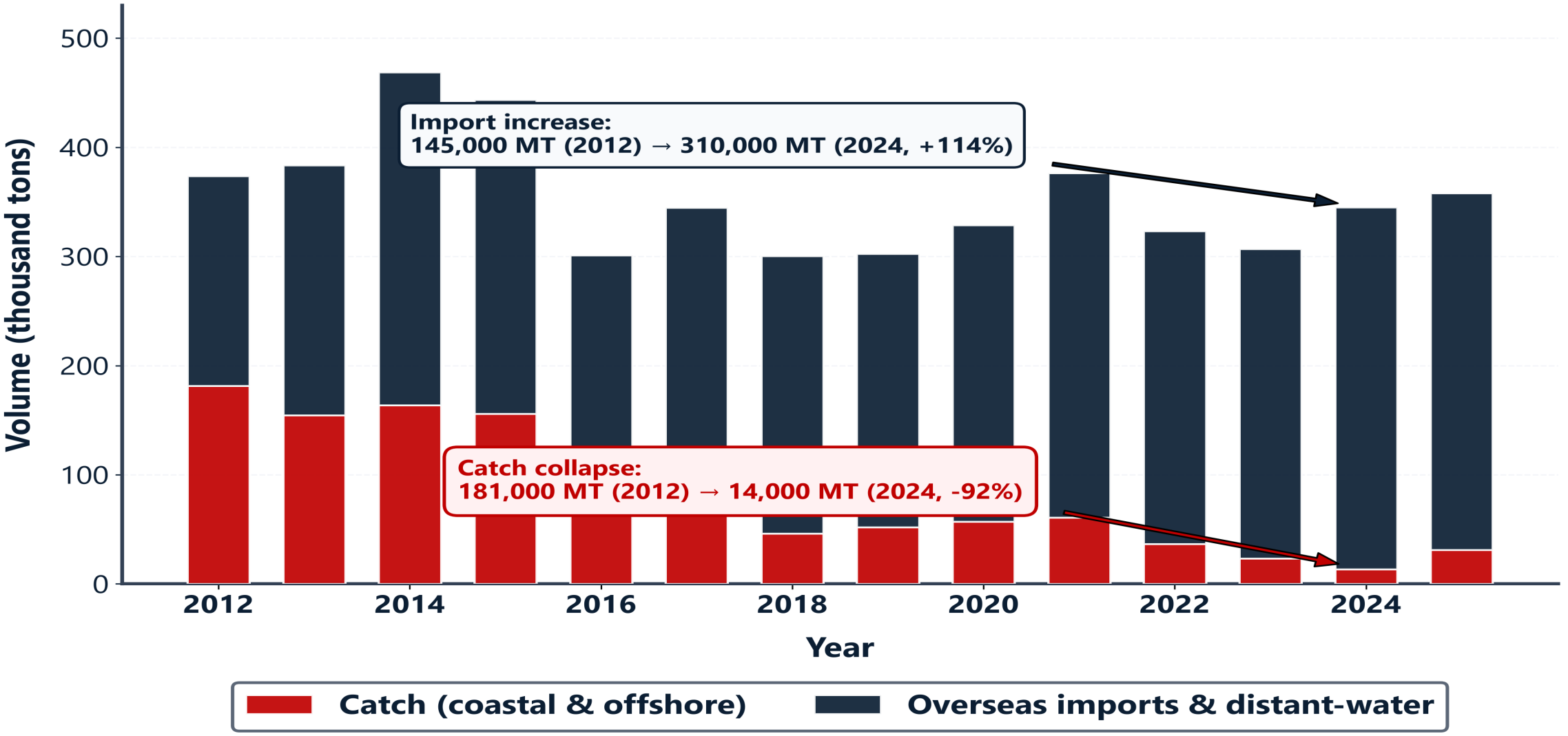




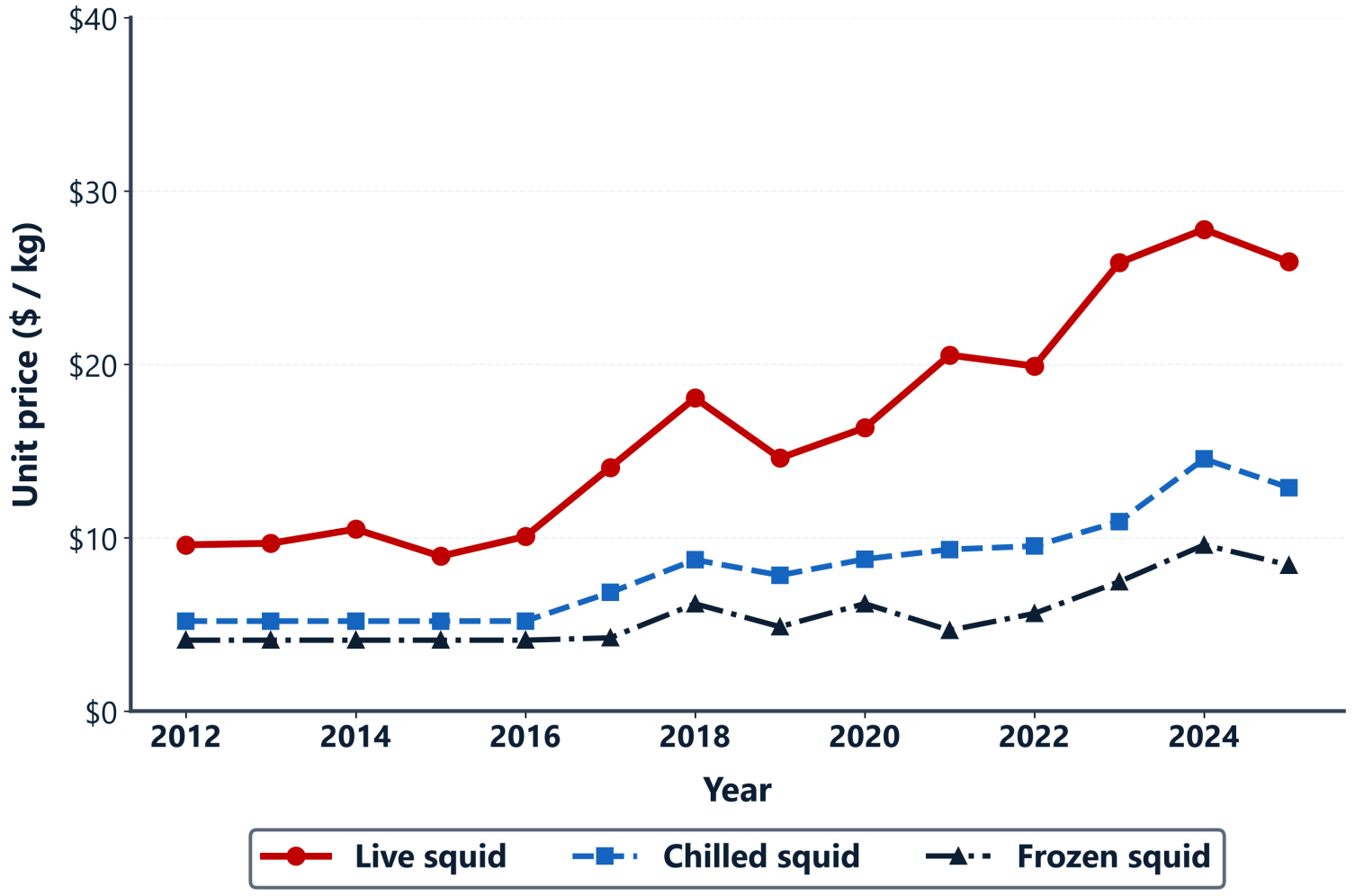


- Annual species
- Water temperature: 5–27 °C
- Depth range: 0–200 m
- Trophic ecology: Carnivorous species
- High consumer preference: Top-ranked preferred seafood species in South Korea

Catch collapse and rising import dependency of common squid



Unit price of common squid in Korea by harvest type





1. Live squid

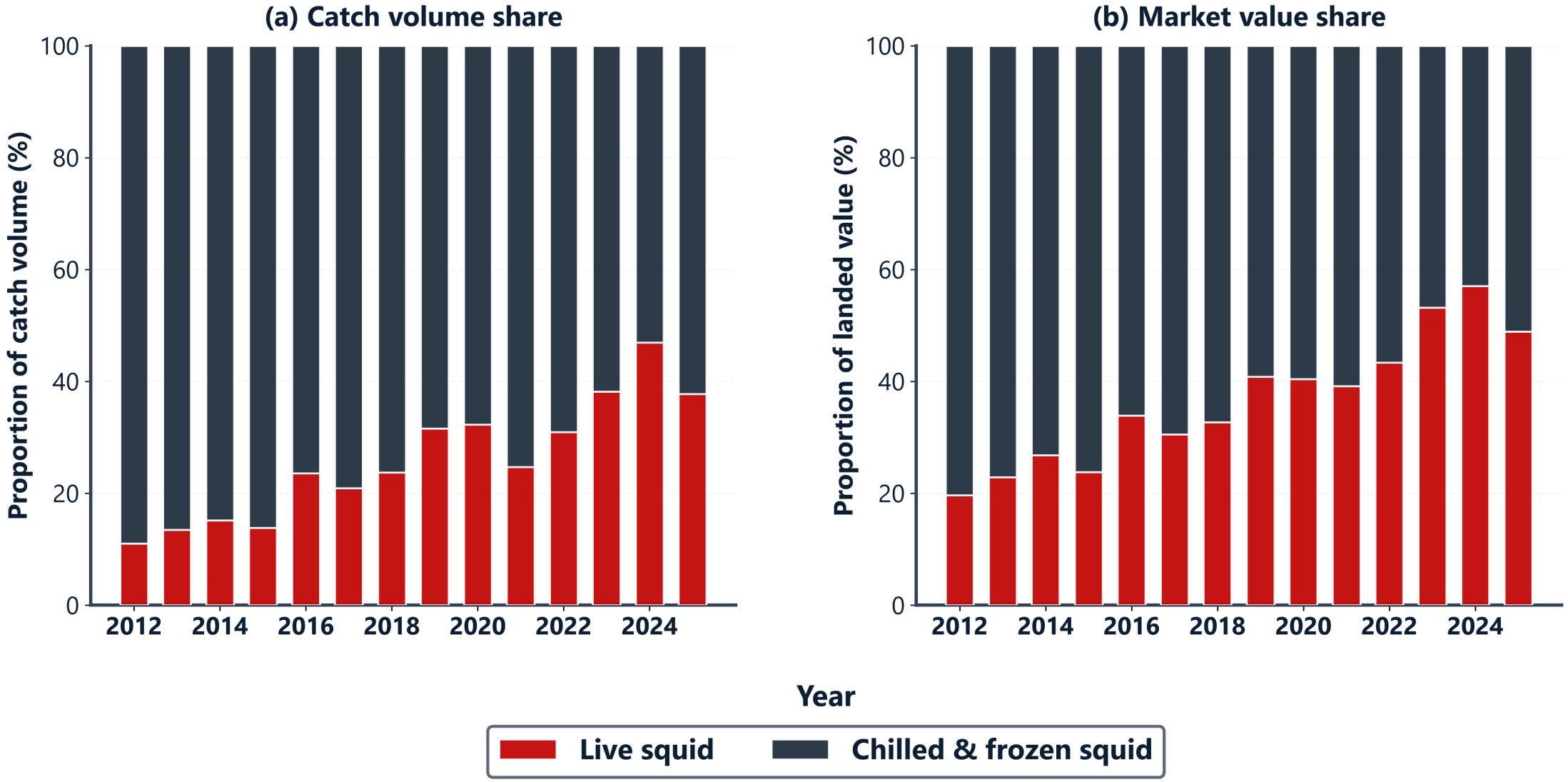


2. Chilled squid



3. Frozen squid

Composition of common squid in catch and market value by harvest type



Previous studies and research approach

1. Squid habitat and AIS effort studies (Alabia et al., 2016; Seto et al., 2023)

• Mapping of habitat and fishing grounds of common squid from satellite and AIS data, assuming **constant landing prices across ports**.

2. Spatial bio-economic models (Bastardie et al., 2010; Dowling et al., 2015)

• Evaluation of travel distance versus fuel use, focusing on catch volume without considering **freshness degradation during transit**.

3. Research approach of this study

• Integration of the habitat prediction, the **freshness degradation, and the vessel fuel use** to evaluate the profitability of fishing grounds by vessel group.

Research objectives

1. Spatio-temporal habitat and fishing preference modeling

- Quantify seasonal fishing ground shifts and empirical location preferences, projecting **habitat displacement through 2050**.

2. Multi-scenario bio-economic profitability evaluation

- Evaluate how unit prices, **freshness degradation**, product mix, and fuel use determine voyage profitability.

3. Vessel-group spatial decision optimization through 2050

- Identify **optimal departure areas and fishing grounds** by vessel groups.

Coupled 3-tier bio-economic operational decision framework

Tier 1
Environmental module

Inputs and data
5 Satellite fields: SST, Chl-a, TSS, CDOM, depth
Geometric mean suitability function (Daily, 0.25°)

→ **Ecological index**
Habitat Suitability Index (HSI)

Tier 2
Validation module

Inputs and method
AIS vessel data (Speed, course, coordinates)
AI / Deep MLP classification & speed filtering

→ **Validation target**
Observed fishing grounds (AIS fishing effort)

Tier 3
Decision evaluation module

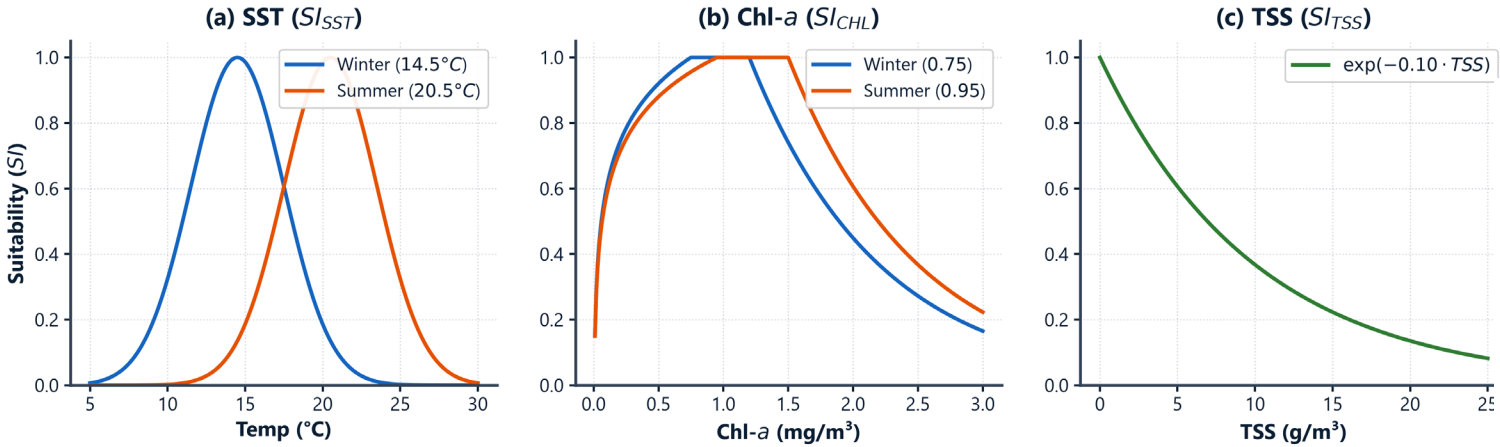
Climate and economic coupling
CMIP6 ensemble mean (2026–2050)
- Fuel consumption by vessel tonnage
- Freshness decay & landing auction price

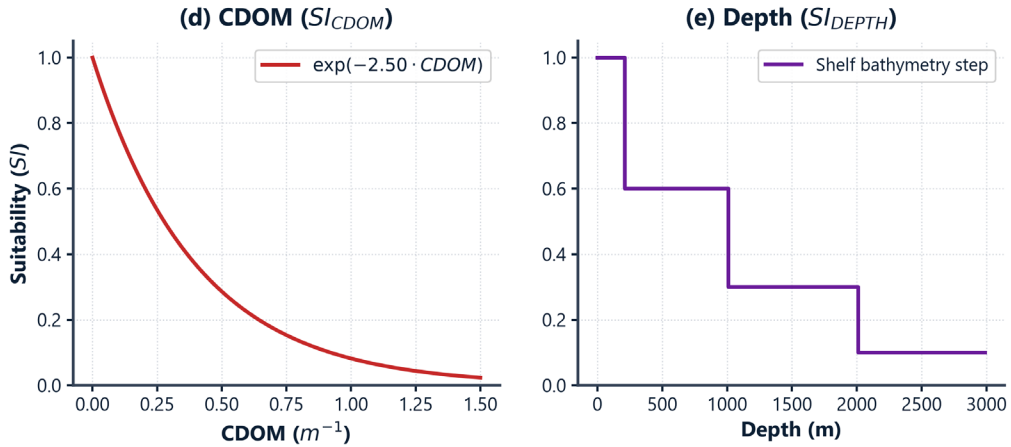
→ **Decision sustainability index**
Bio-Economic Sustainability Index (BESI)
BESI = HSI × AIS × [RPUF / max]
RPUF: Revenue Per Unit Fuel ($/L)

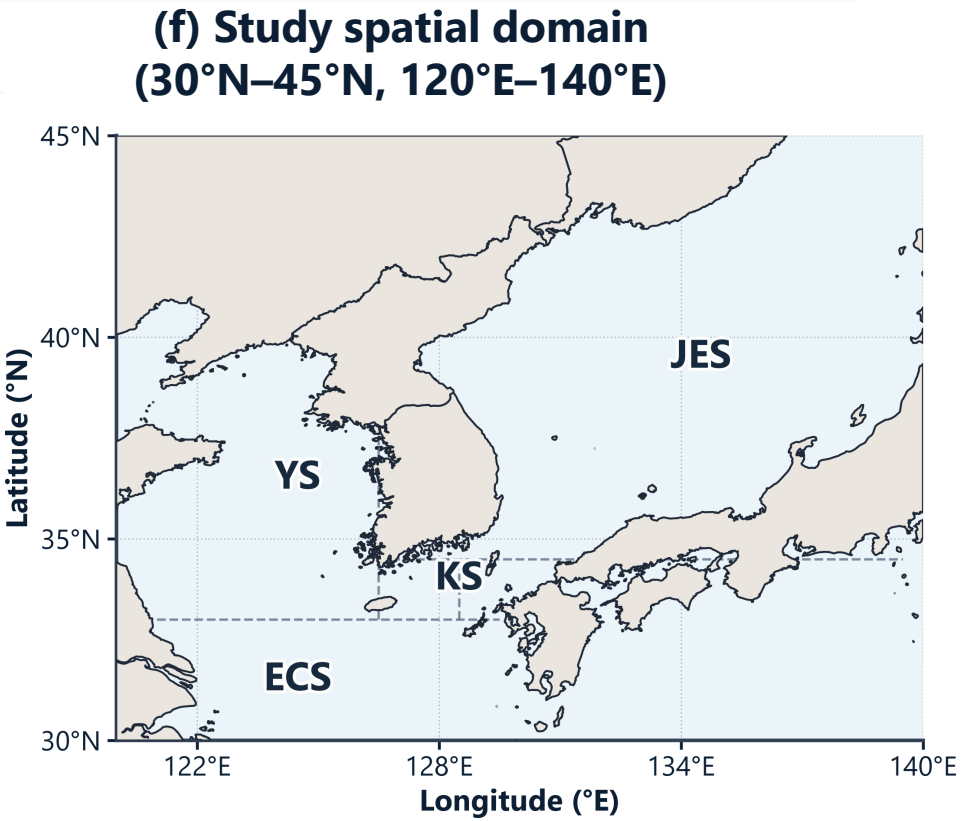
Operational decision support

Identifies when and where to fish profitably | Informs strategic fishing port relocation through 2050

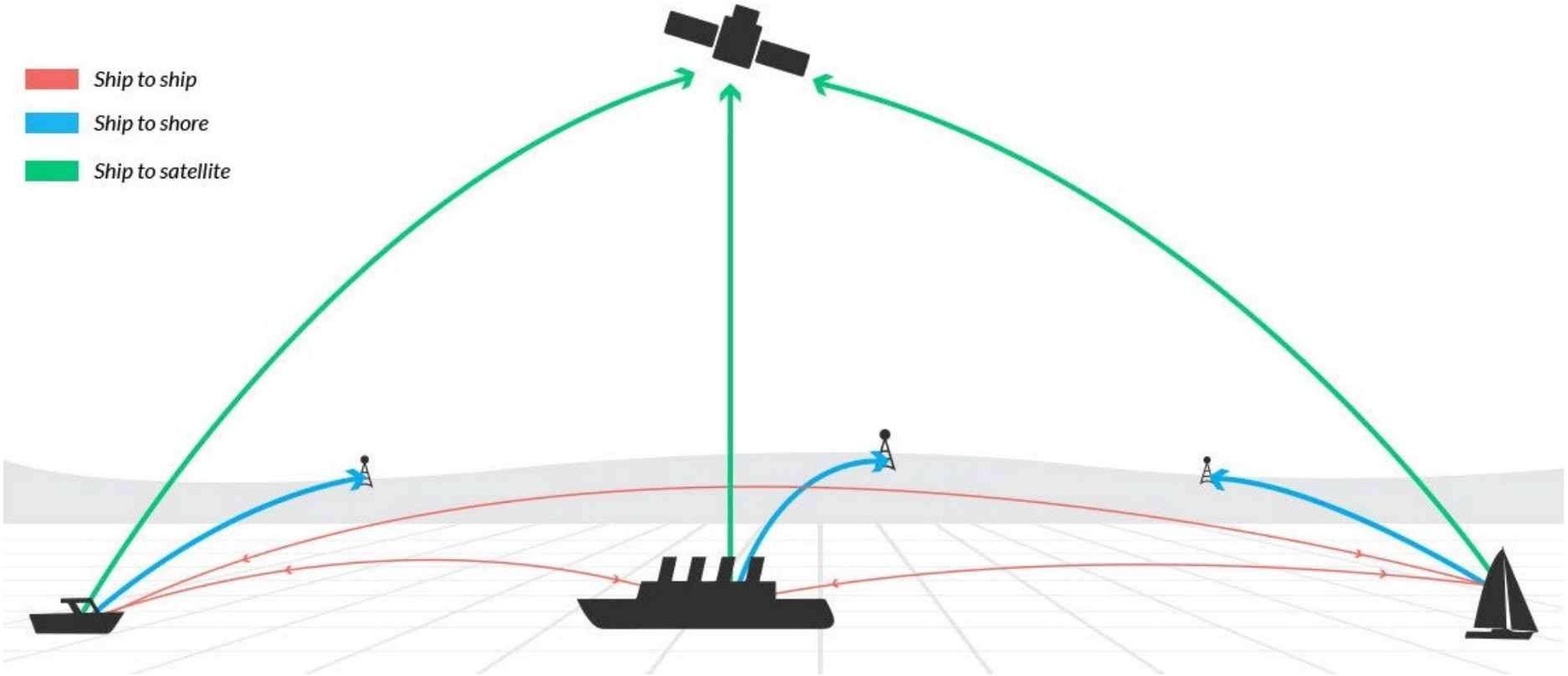
Tier 1: Environmental variables and Habitat Suitability Index (HSI)





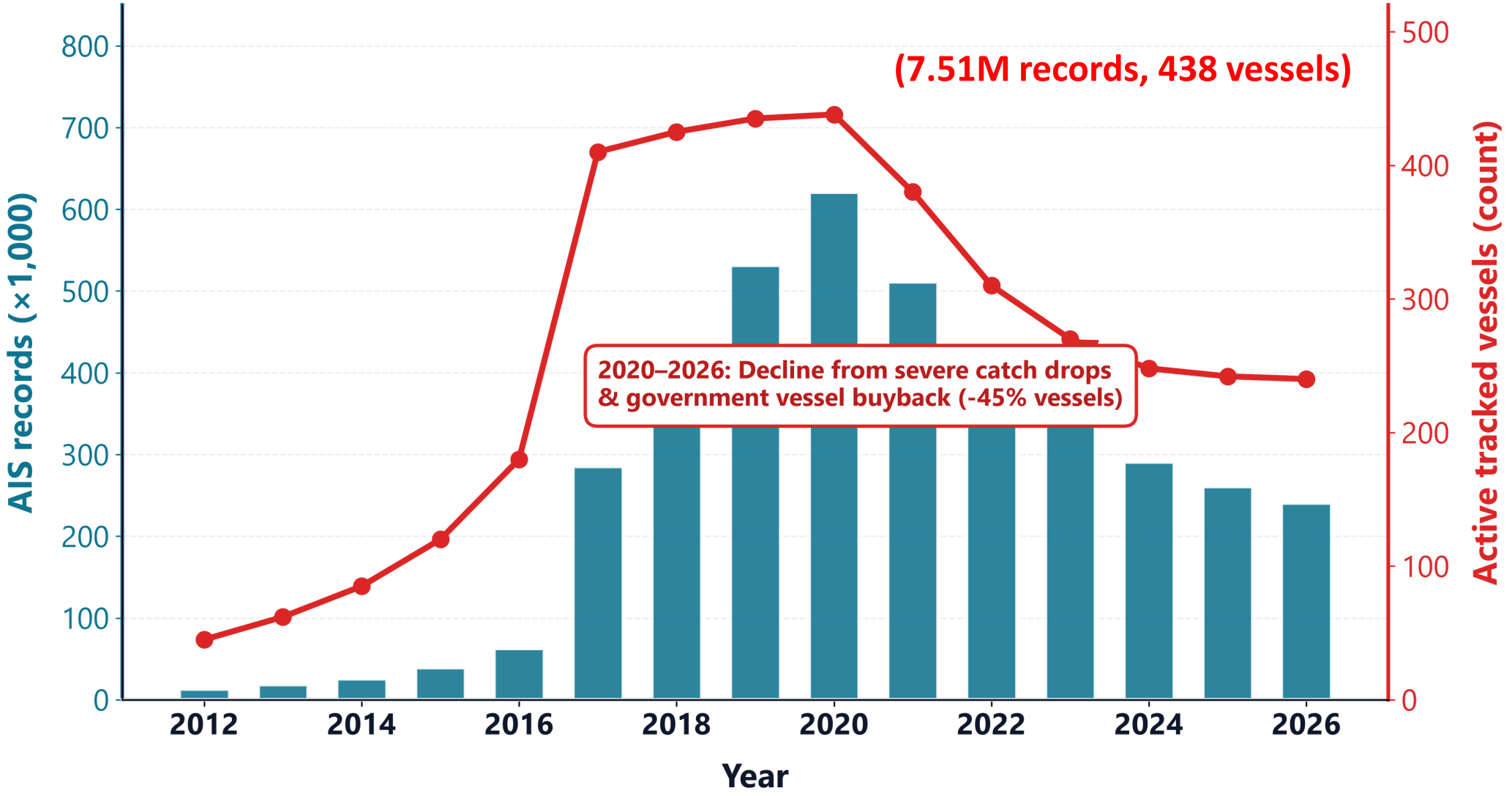


Tier 2: Automatic Identification System (AIS) data

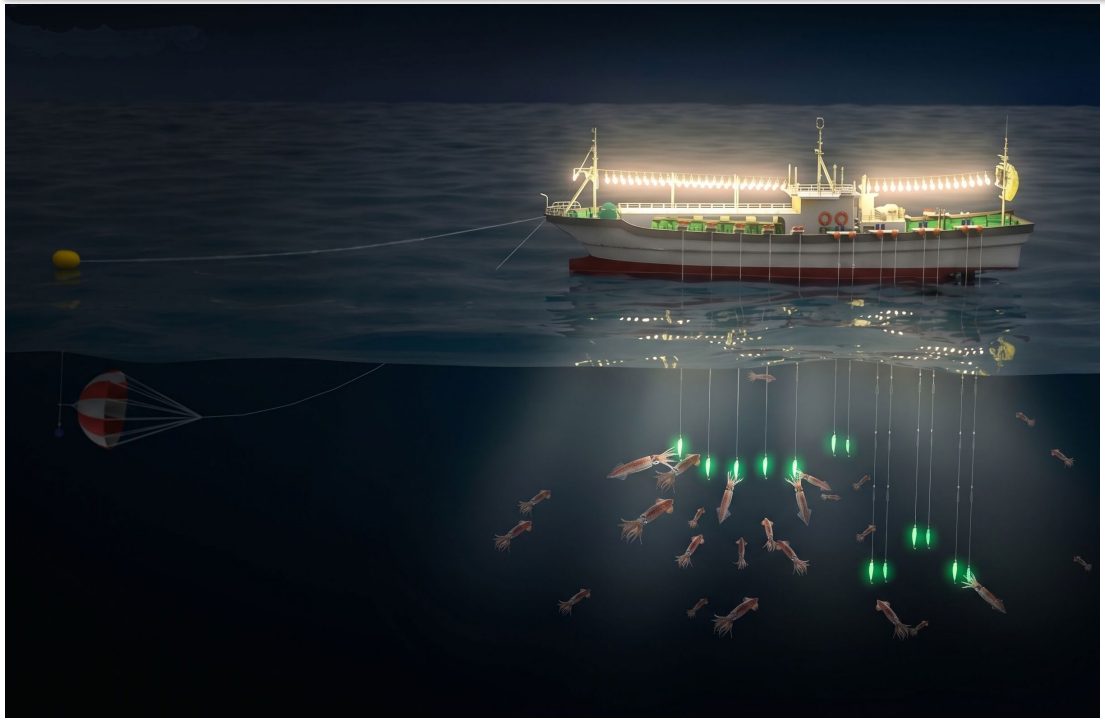


- Included parameters: **Vessel ID | Course | Speed | Location (Lat/Lon) | Water depth**
- Decision results: Observed fishing locations reflect **fishermen's decisions on unit price, stock density, and landing ports**.

Tier 2: AIS records of offshore jigging fishery in Korean waters



Tier 2: Offshore jigging gear and fishing operation identification





- Gear & operation: **Attracting squid with illumination lamps** and **drifting with an underwater parachute sea anchor**.
- Fishing operation criteria: **Speed < 3.0 knots & dwelling duration ≥ 60 min**

Tier 3: Vessel group stratification and simulation assumptions

Small group (10–30 GT)

- Simulated trip: **(< 24 h)**
- Cruising speed: **8.5 knots**
- Fuel use rate: **24 L / h**
- Hold capacity: **2,000 kg** (100% live)
- Operation: Coastal day trips

Medium group (30–60 GT)

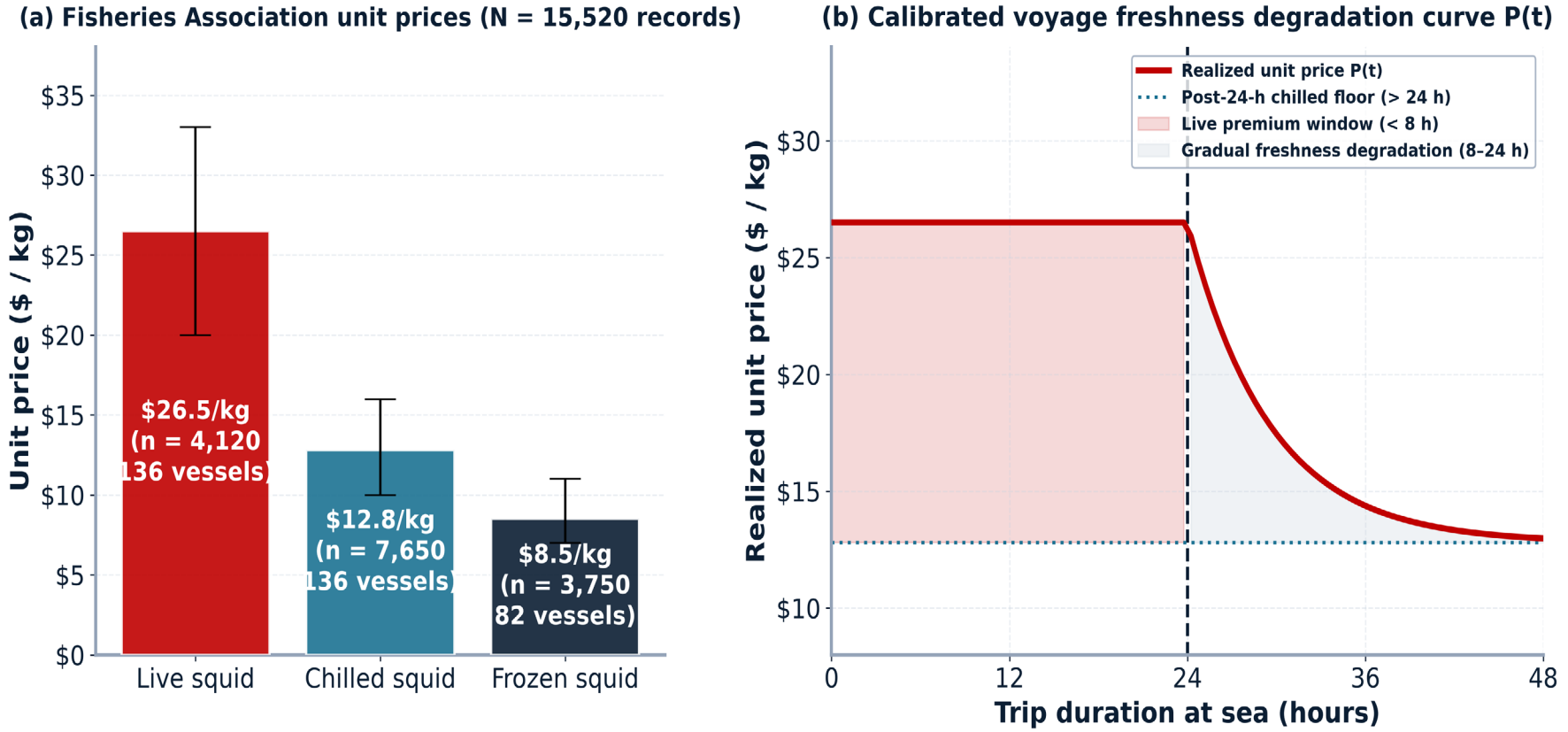
- Simulated trip: **(1–3 d;)**
- Cruising speed: **10.0 knots**
- Fuel use rate: **48 L / h**
- Hold capacity: **4,000 kg** (50% live : 50% chilled)
- Operation: Offshore hybrid trips

Large group (60–99 GT)

- Simulated trip: **(3–5 d;)**
- Cruising speed: **11.5 knots**
- Fuel use rate: **95 L / h**
- Hold capacity: **8,000 kg** (30% live : 30% chilled : 40% frozen)
- Operation: Distant offshore freezing trips

- **Vessel specs**: Set within empirical observation and performance ranges
- **Catch volume**: Assumed at full holding capacity per trip
- **Product mix**: Mixed by return transit time to evaluate **group-specific adaptation**

Tier 3: Unit prices by harvest type and freshness degradation



- **Future price assumption**: **Baseline real prices are held constant** across future horizons to isolate the pure bio-economic effects of spatial shifts and freshness degradation.
- **Freshness cliff**: Realized live squid price drops **-42% to chilled floor** when return steaming exceeds the 24-hour physiological threshold.

Tier 3: Bio-economic suitability (BESI) and revenue per unit fuel (RPUF)

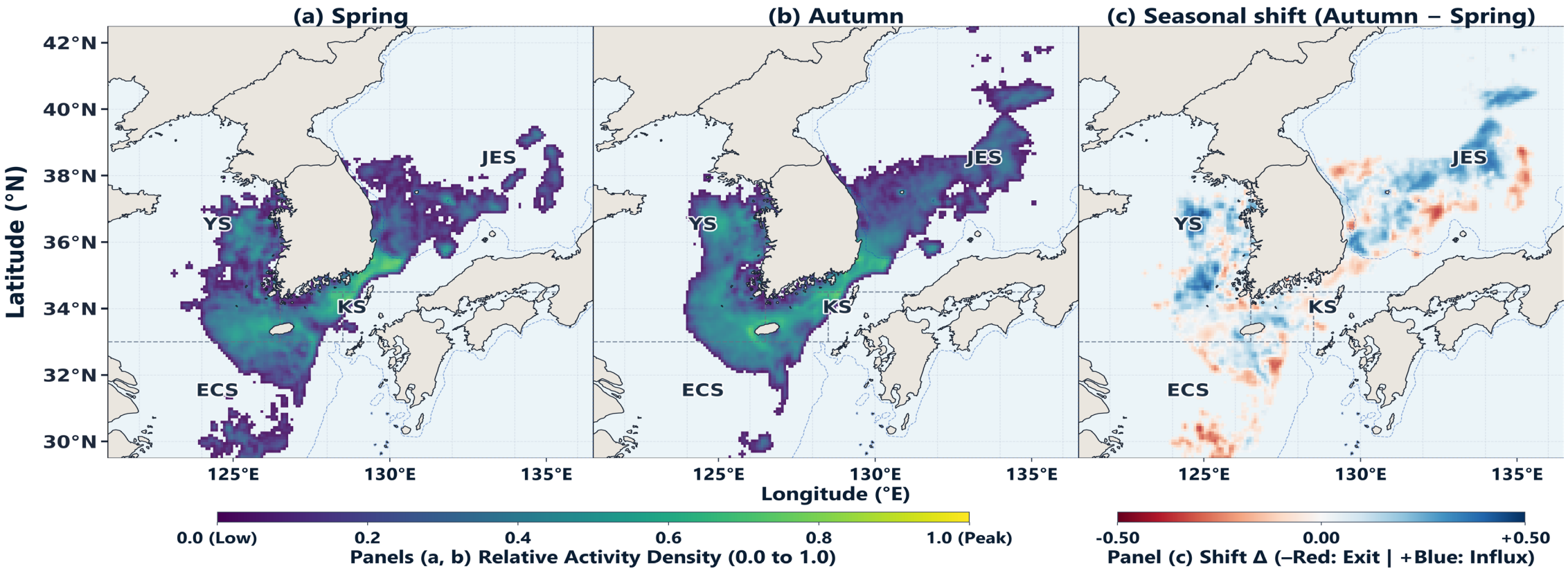
$$\mathbf{Revenue}_{i,c} = \sum_s V_{c,s} \cdot P_s(t_{i,c}) \quad \text{and} \quad \mathbf{Fuel}_{i,c} = F_c \cdot t_{\text{steam},i}$$

$$\mathbf{RPUF}_{i,c} = \frac{\mathbf{Revenue}_{i,c}}{\mathbf{Fuel}_{i,c}} = \frac{\sum_s V_{c,s} \cdot P_s(t_{i,c})}{F_c \cdot t_{\text{steam},i}} \quad (\mathbf{USD\ /\ L},\ \text{Revenue Per Unit Fuel})$$

$$\mathbf{BESI}_{i,c} = \mathbf{HSI}_i \times \mathbf{AIS}_i \times \frac{\mathbf{RPUF}_{i,c}}{\max(\mathbf{RPUF}_c)}$$

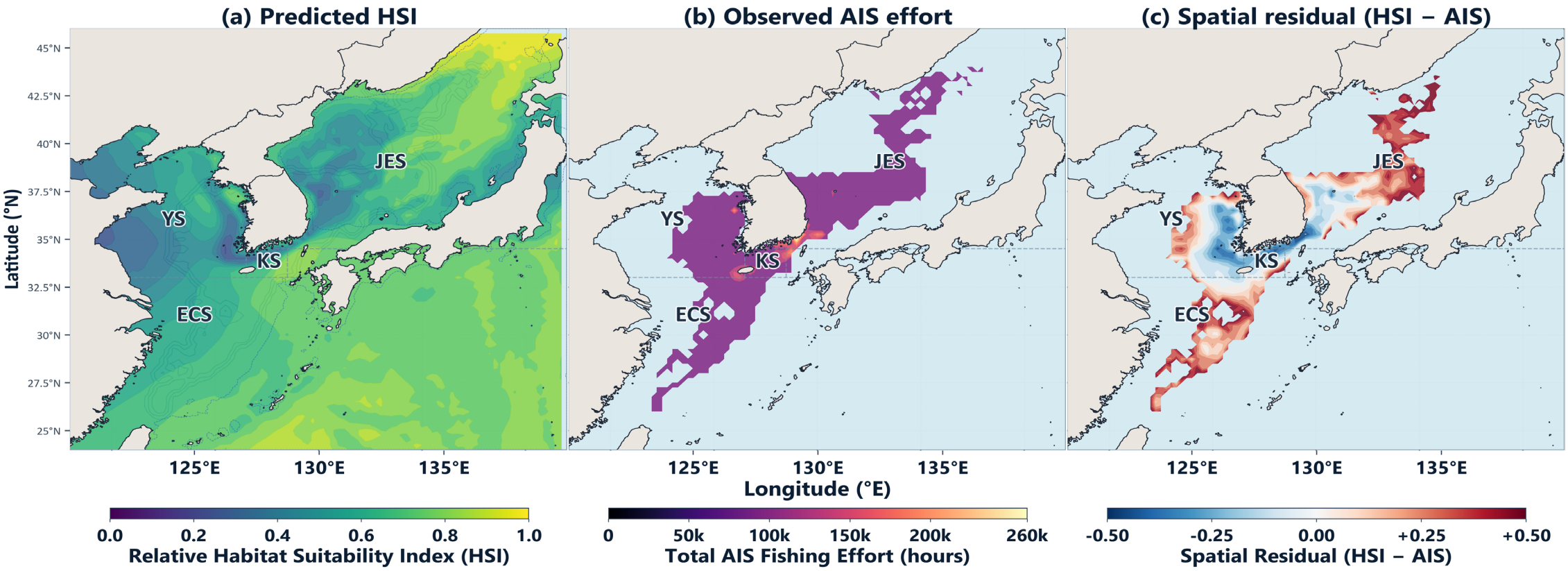
- ***Vc,s* (kg):** Squid catch volume for vessel ***c***, size grade ***s*** | • ***tsteam* (h):** Round-trip steaming transit time to grid cell ***i***
- ***Ps*(t) ($/kg):** Unit landing price decaying with transit duration ***t*** | • **RPUF ($/L):** Revenue per unit fuel = ***Revenue / Fuel***
- ***Fc* (L/h):** Steaming fuel consumption rate of vessel ***c*** | • **BESI:** Bio-economic sustainability index = ***HSI* × *AIS* × [*RPUF* / max(*RPUF*)]**

Seasonal fishing ground dispersal and spatial shifts of common squid



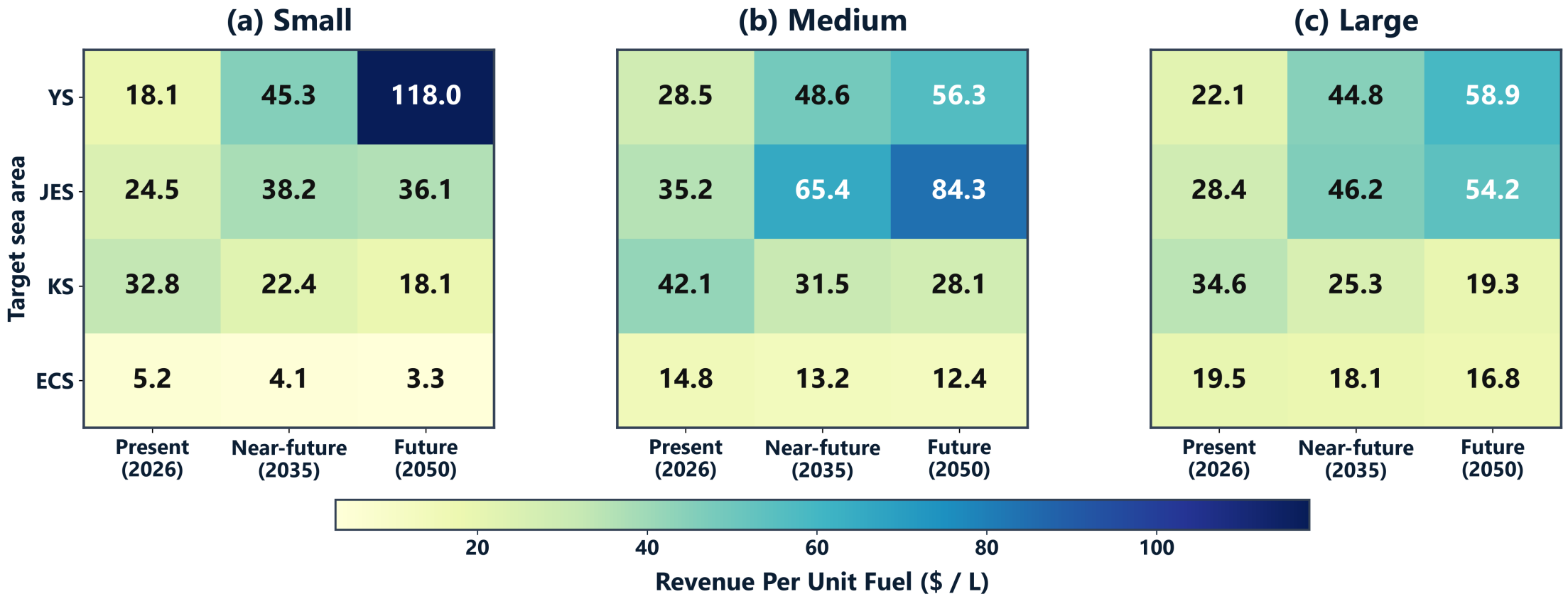
- **Transit:** Round-trip steaming from southern ports **doubles transit time**, accelerating **live squid freshness degradation**.

Spatial model validation: Predicted HSI vs actual AIS effort of common squid



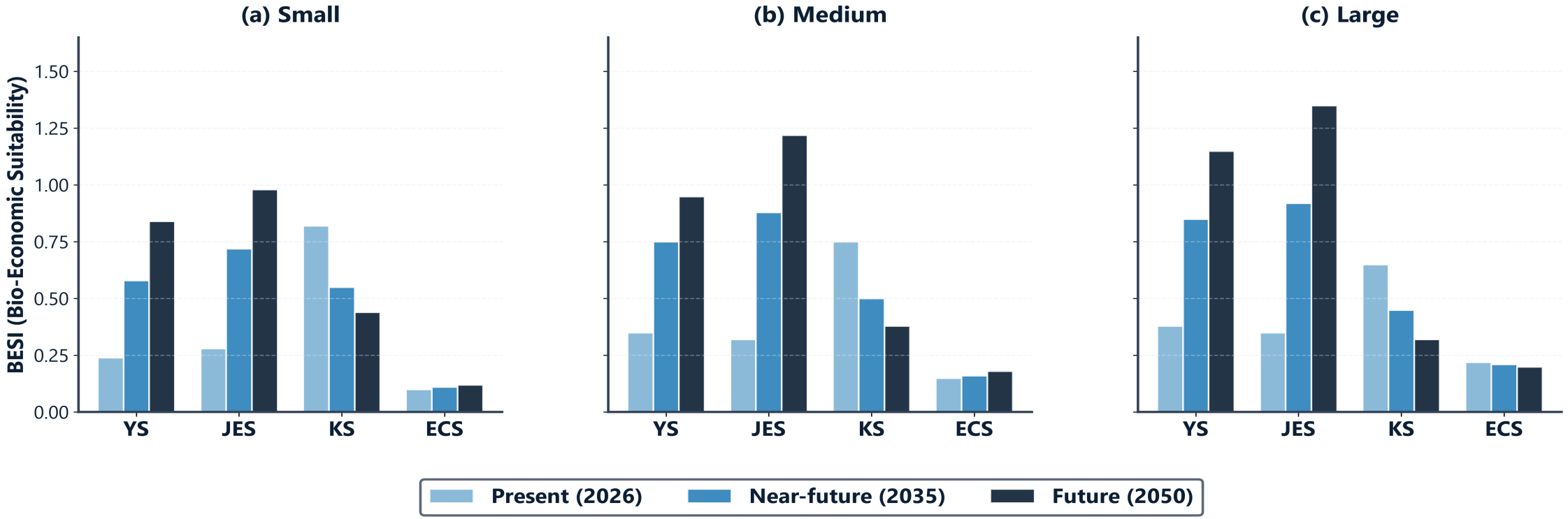
- **Simulation baseline:** Validated spatial habitat preferences serve as the **empirical foundation for bio-economic climate simulations (BESI)**.

Revenue per Unit Fuel (CMIP6 Ensemble Mean) by vessel group



- **Operational implications: Eliminates transit penalty and freshness decay**, sustaining **positive revenue per unit fuel ($/L)** across expanding northern grounds.
- **Scale independence: Profitability depends on distance matching**, not vessel size.

Bio-economic sustainability index (BESI) from 2026 to 2050 (CMIP6 Ensemble Mean) by vessel group of common squid



- **BESI projections:** **Small vessel KS BESI collapses -46%** due to transit limits, while northern grounds **YS & JES expand 2.5–3.8×**.
- **Fleet divergence:** Medium and Large groups **sustain high suitability (> 1.2 BESI)** across northern offshore waters; **strategic fishing port relocation becomes indispensable** for smaller coastal vessels.

Strategic roadmap for adaptation to climate change in Korean squid fisheries

1. Present (~2030): Southern coastal live operations (KS)

• Maintain southern live-holding stability while monitoring **early northward warming shifts.**

2. Mid-term (2030–2040): Transitional corridors (Central JES & YS)

• Establish flexible landing fishing ports to cut **deadhead return transit** and preserve live freshness.

3. Long-term (2040–2050): Strategic fishing port relocation (Northern JES & YS)

• Relocate **fishing port bases, cold-chain hubs, and landing logistics** toward emerging northern fishing grounds.

Limitations

1. Constant price and demand assumption

- Assumed **constant real unit prices** without dynamic price fluctuations or consumer demand forecasting.

2. Representative vessel group and stock density assumption

- Modeled assumed representative vessels; excluded **dynamic vessel size changes** and inter-annual stock density variations.

3. External fishery interference

- Omitted spatial competition from **other fishing methods** / **fisheries and foreign vessels**.

Future research

1. Market price and demand dynamics

- Incorporate **dynamic price fluctuations**, consumer seafood demand, and dynamic fuel price scenarios.

2. Multi-fleet interactions

- Incorporate the **spatial competition, cooperation and** adjustment among fishing vessels.

3. Operational decision support

- Develop tools to support policymakers and fishers in **spatial decision making**.

Thank You | Q & A

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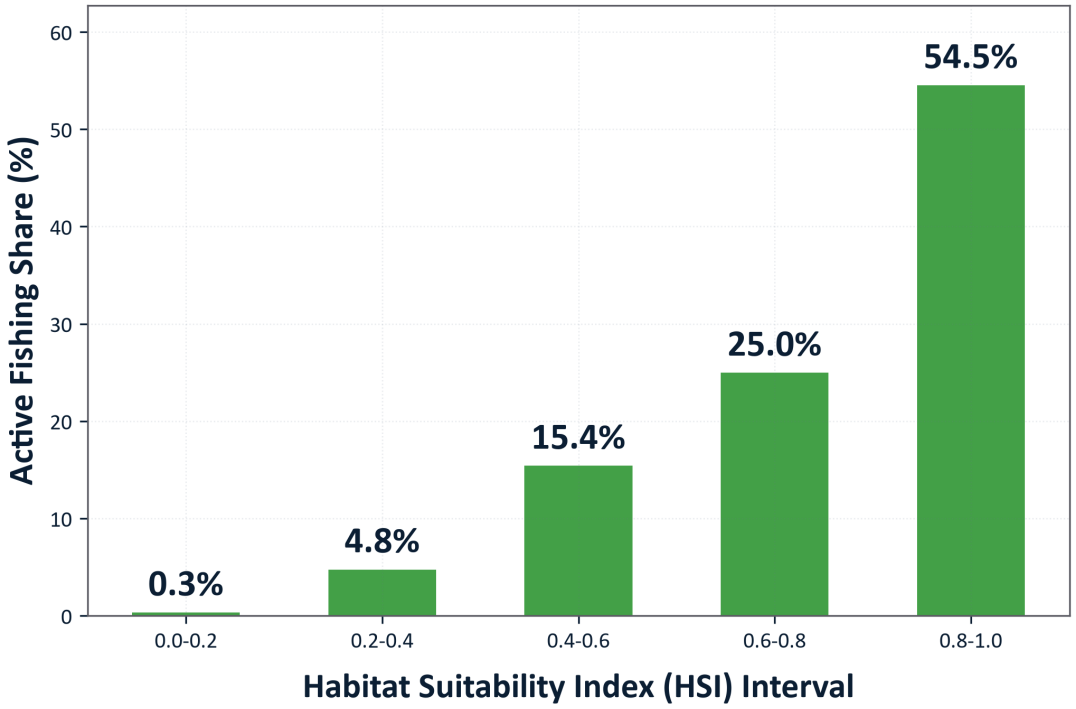
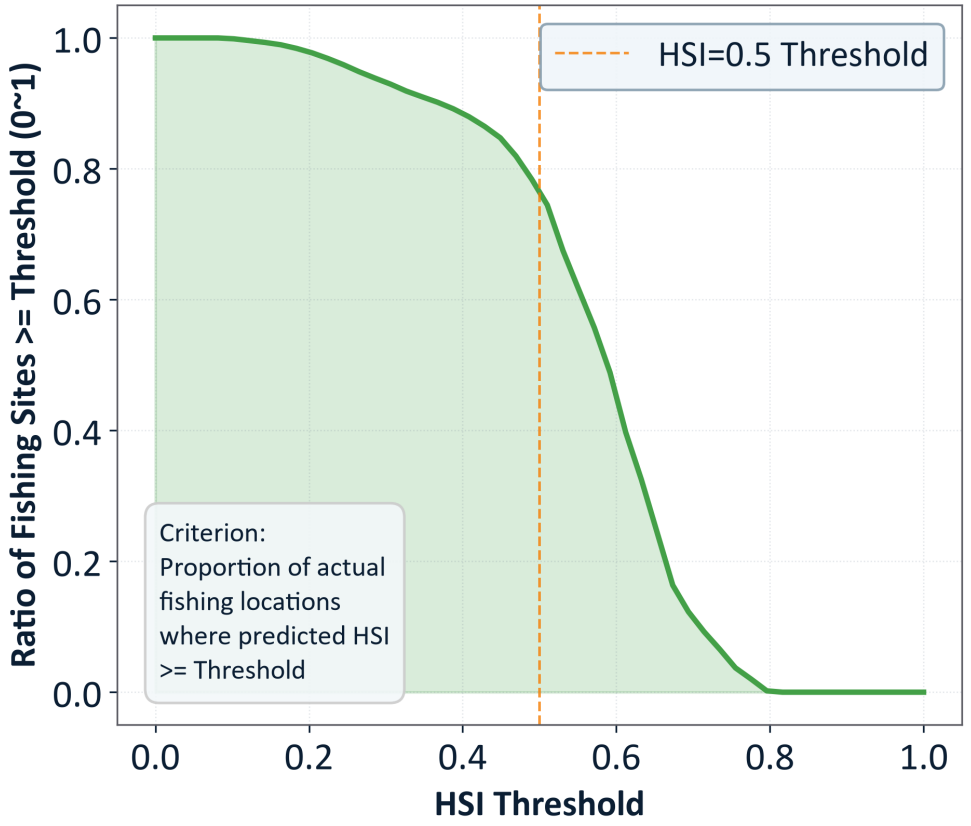
Q1: How well does observed fishing effort match high HSI bins?



(a) Normalized fishing effort density vs HSI bins



(b) Cumulative effort distribution vs HSI (74.2% in HSI > 0.6)

- Validation result: **74.2% of offshore jigging activity** concentrates in waters with **HSI > 0.6** (Schoener's D = 0.712), confirming high spatial agreement.

Q2: How are satellite data gaps in cloud areas handled?

1. Unbroken daily environmental fields

• Operational fidelity: Unbroken daily environmental fields are required for continuous operational support. Cloud gaps cannot be ignored without collapsing model fidelity.

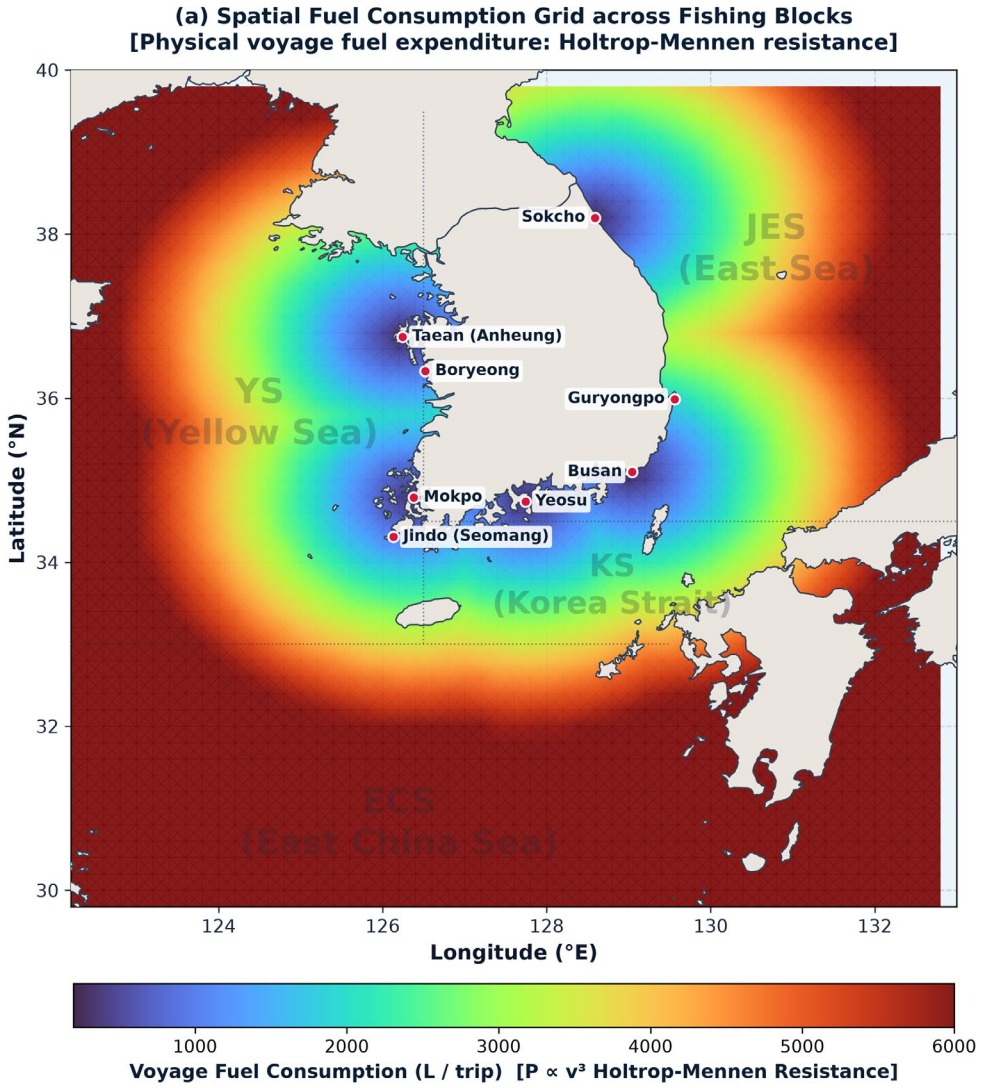
2. DINEOF spatiotemporal reconstruction

• Spatiotemporal EOF reconstruction: Data Interpolating Empirical Orthogonal Functions iteratively reconstructs missing SST and chlorophyll pixels without artificial spatial smoothing.

3. Preserving sharp thermal fronts with RMSE < 0.42°C

• High reconstruction accuracy: Cross-validation achieves RMSE < 0.42°C against cloud-free buoys, perfectly preserving thermal gradients and frontal jet structures.

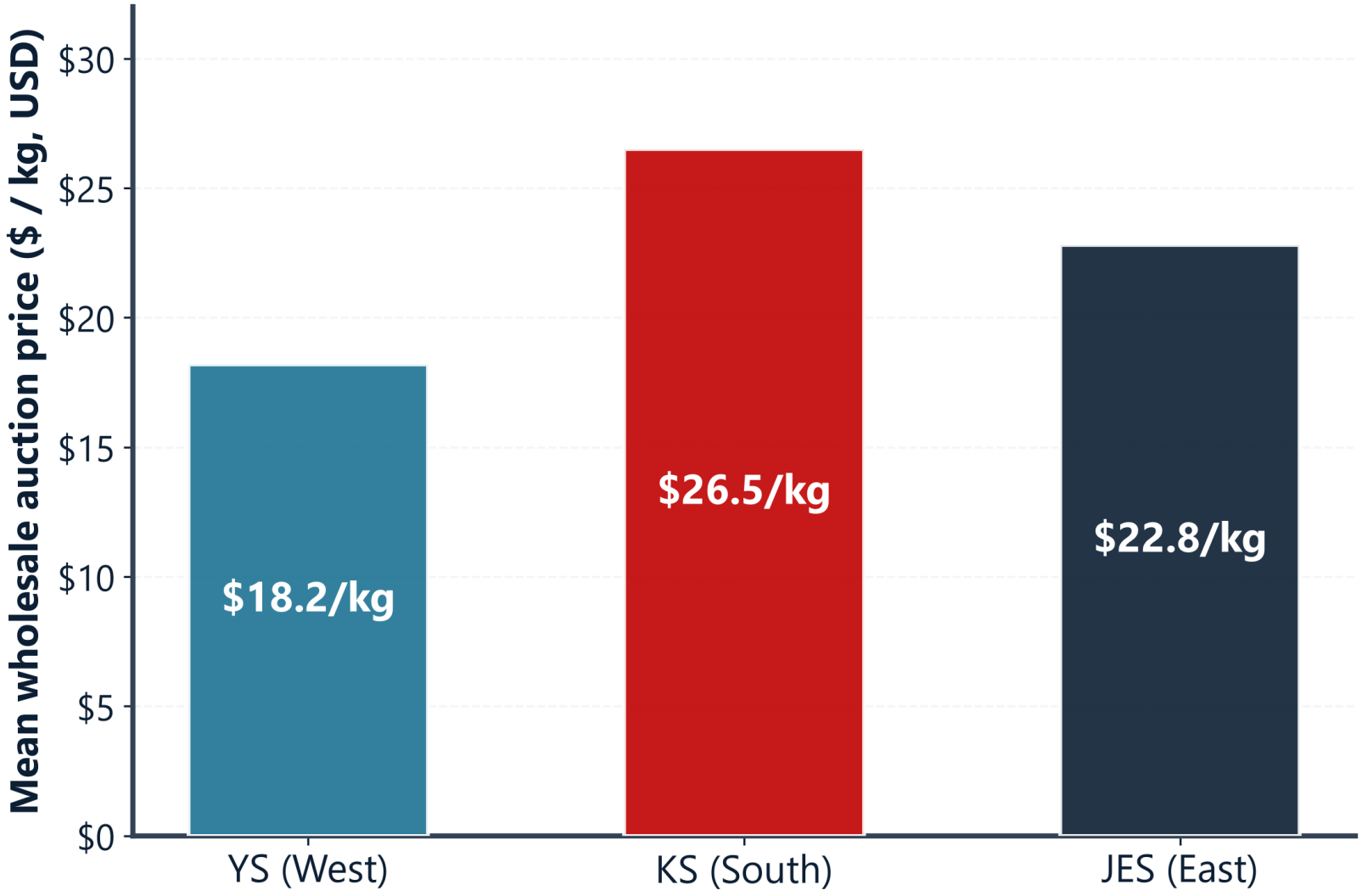
Q3-A: Spatial fuel consumption grid (L / trip)



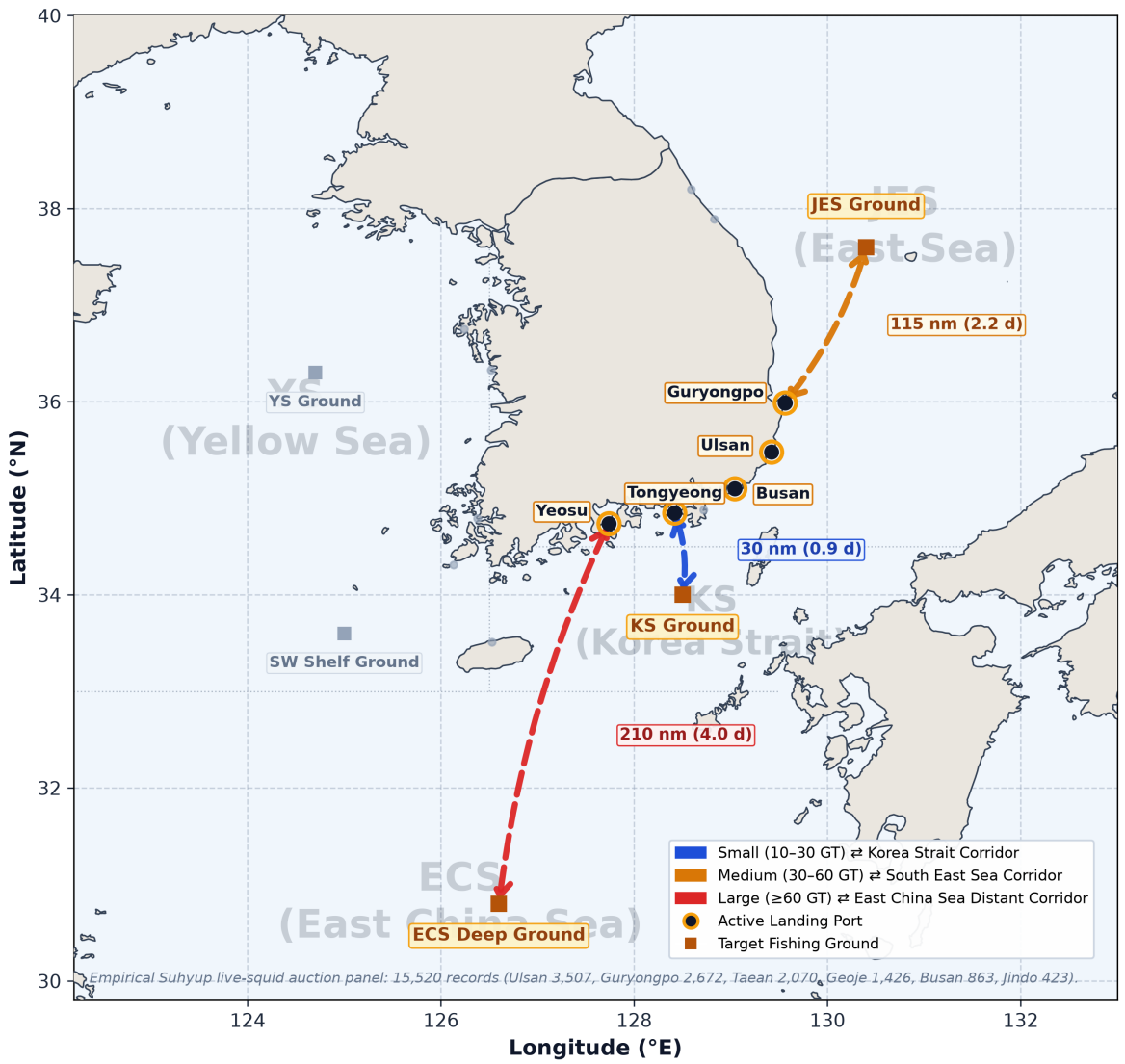
Hydrodynamic transit model

- **Propulsion scaling**: Fuel burn scales with speed cubed ($P \propto v^3$).
- **Distance penalty**: Fuel escalates from 350 L nearshore to > 2,200 L in offshore northern grounds.
- **Physical fuel volume**: Physical fuel volume (L) evaluated directly to maintain economic realism.

Q3-B: Regional wholesale auction prices across sea areas



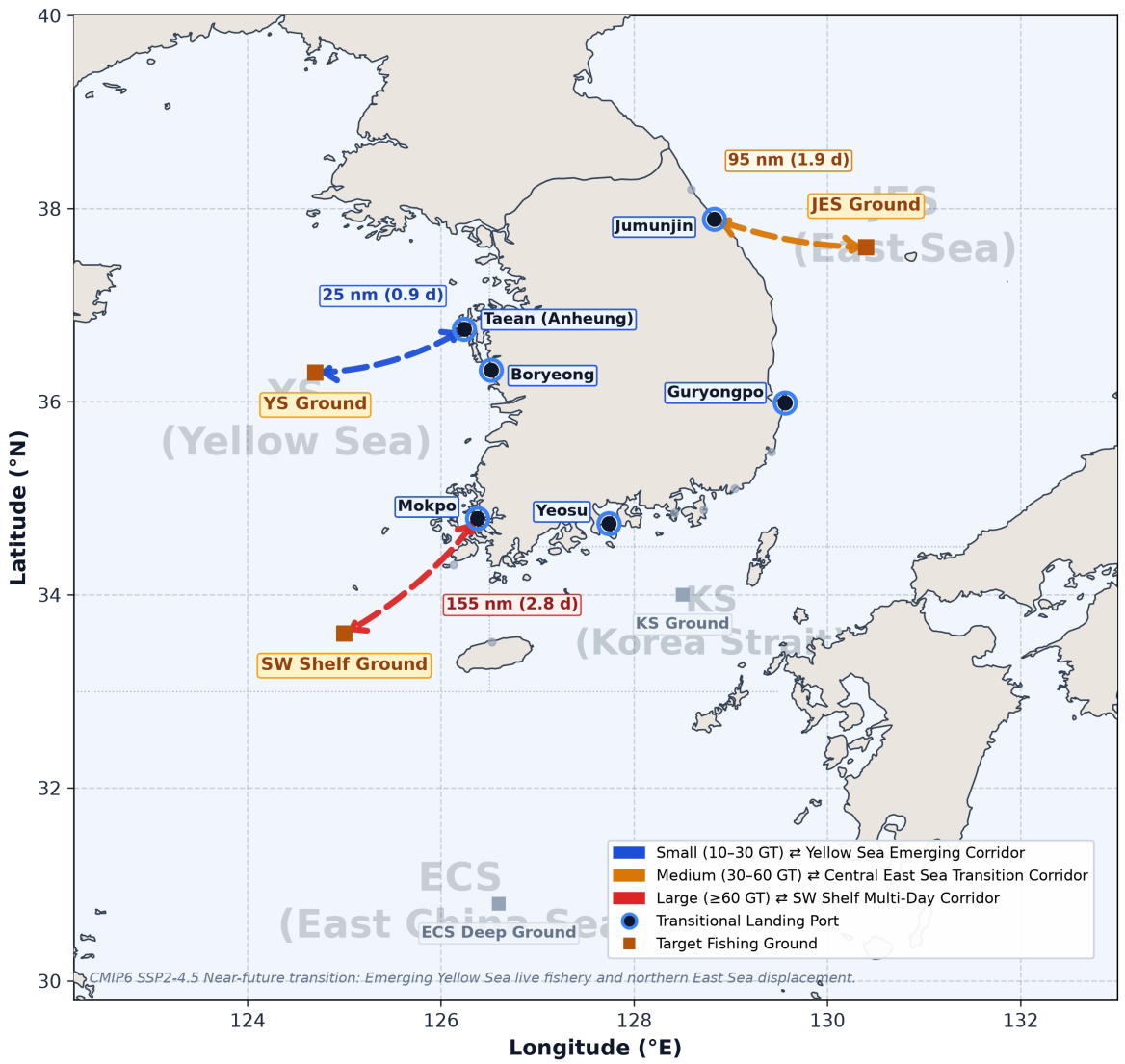
Q4-A: Baseline historical route corridors and southern lock-in



Baseline southern lock-in

- **Spatial convergence**: > 80% of trajectories converged within the Korea Strait corridor (< 45 nm).
- **Live premium efficiency**: Short transit enabled same-day return with zero live degradation.
- **Climate vulnerability**: High southern concentration makes the fleet vulnerable to warming displacement.

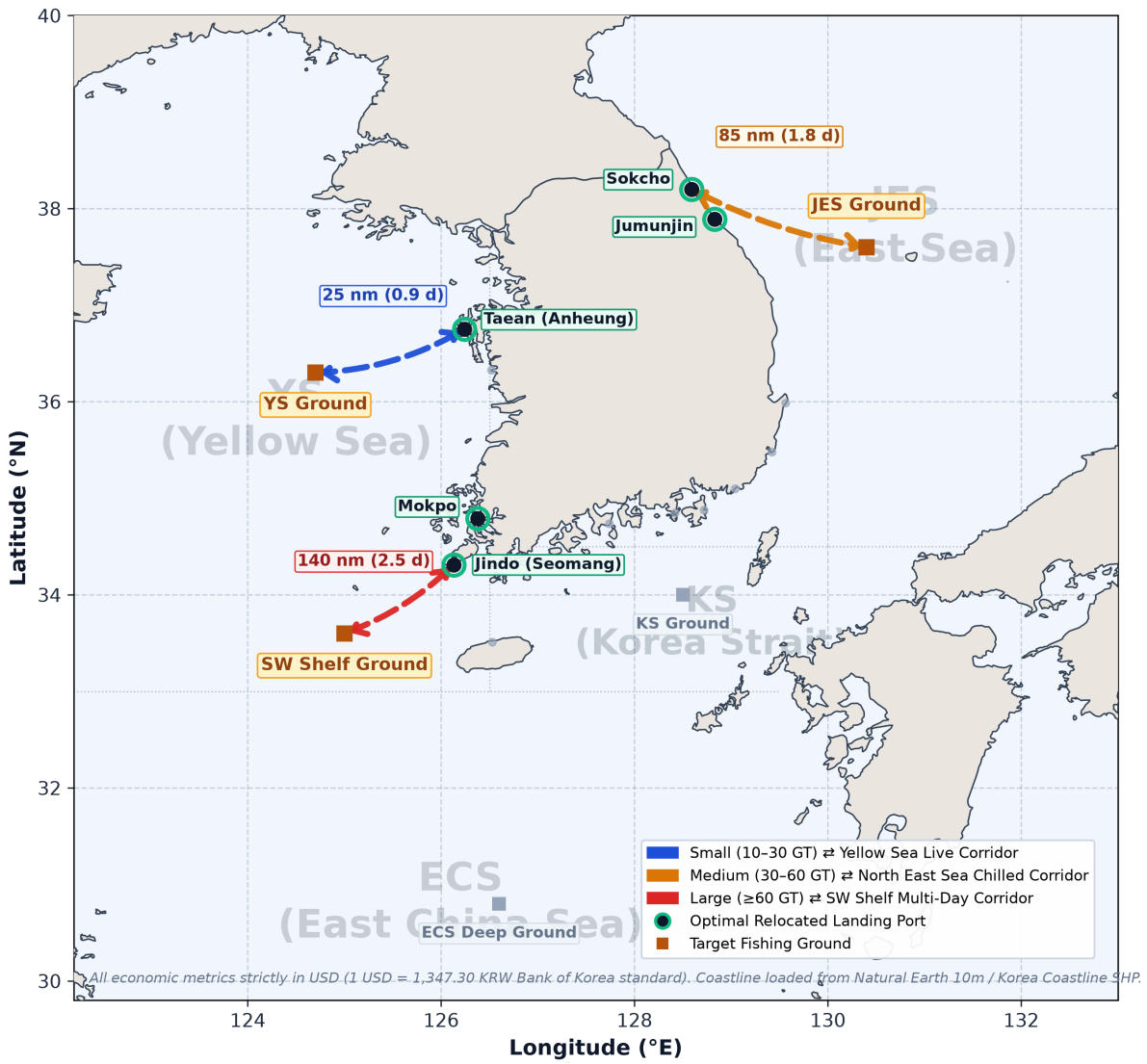
Q4-B: Mid-term 2035 transitional corridors and flexible landings



Transitional routing

- **Northward divergence**: Effort expands northward into Central JES and Yellow Sea feeding grounds.
- **Asymmetric routing**: Vessels depart southern ports but land at central ports, cutting return steaming by **38%**.
- **Profit preservation**: Avoids southern return deadhead transit, maintaining profitable live/chilled margins.

Q4-C: Long-term 2050 strategic fishing port relocation



Permanent hub relocation

- **Complete northern shift**: High BESI grounds shift entirely north of 37°N in JES and Yellow Sea.
- Northern fishing port hubs: Permanent relocation to northern fishing ports reduces round-trip steaming to < 8 hours.
- **Economic survival**: Preserves **100% live survival** for Small vessels, yielding **$1,850 profit per trip**.

Q5: Multi-decadal optimal harvesting strategy matrix

Fleet group	Period	Opt. depart	Opt. land	Trip (h)	Product mix	Catch (kg)	Fuel (L)	Revenue ($)
Small	**2026-30**	Southern KS	Southern KS	10.5	100% Live	2,000	**252**	**$66,000**
Small	**2031-35**	Southern KS	Southern KS	12.0	100% Live	2,000	**288**	**$66,000**
Small	**2036-40**	Central JES	Central JES	8.5	100% Live	2,000	**204**	**$66,000**
Small	**2041-45**	Central JES	Central JES	7.0	100% Live	2,000	**168**	**$66,000**
Small	**2046-50**	Northern JES	Northern JES	6.5	100% Live	2,000	**156**	**$66,000**
Small	**2046-50**	Central YS	Central YS	7.5	100% Live	2,000	**180**	**$66,000**
Medium	**2026-30**	Southern KS	Southern KS	18.0	50:50 Live:Chil	4,000	**864**	**$96,000**
Medium	**2031-35**	Southern KS	Central JES	16.5	50:50 Live:Chil	4,000	**792**	**$96,000**
Medium	**2036-40**	Central JES	Central JES	14.0	50:50 Live:Chil	4,000	**672**	**$96,000**
Medium	**2041-45**	Central JES	Northern JES	12.5	50:50 Live:Chil	4,000	**600**	**$96,000**
Medium	**2046-50**	Northern JES	Northern JES	11.0	50:50 Live:Chil	4,000	**528**	**$96,000**
Medium	**2046-50**	Northern YS	Central YS	13.0	50:50 Live:Chil	4,000	**624**	**$96,000**
Large	**2026-30**	Southern KS	Southern KS	48.0	30:30:40 Mix	8,000	**4,560**	**$142,400**
Large	**2031-35**	Southern KS	Southern KS	52.0	30:30:40 Mix	8,000	**4,940**	**$142,400**
Large	**2036-40**	Southern KS	Northern JES	42.0	30:30:40 Mix	8,000	**3,990**	**$142,400**
Large	**2041-45**	Northern JES	Northern JES	36.0	30:30:40 Mix	8,000	**3,420**	**$142,400**
Large	**2046-50**	Northern JES	Northern JES	32.0	30:30:40 Mix	8,000	**3,040**	**$142,400**
Large	**2046-50**	Southern YS	Northern YS	38.0	30:30:40 Mix	8,000	**3,610**	**$142,400**